THE USE OF SILICON TRANSISTORS IN BROADCAST RECEIVERS

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In this note the effects of germanium and silicon transistors on circuit operation are compared, considerations in designing with silicon transistors discussed, and complete performance data given on two broadcast receivers constructed with silicon planar transistors.

I. COMPARISON OF SILICON AND GERMANIUM TRANSISTORS

The important differences between silicon and germanium transistors used for entertainment applications are shown with comparative values in Table I and their effects on circuit operation are discussed below:

TABLE I

Comparison of Silicon and Germanium Entertainment Transistors

Parameter	Silicon	Germanium
Polarity of Majority of Devices	NPN	PNP
Maximum Junction Temperature Rating (T_J(max))	125°C to 200°C	70°C to 100°C
Leakage Currents (I_{CBO})	Typically 10 to 10^3 less than germanium	
Cut-off Frequencies (f_T)	40 Mc to 1000 Mc	100 Kc to 1000 Mc
Base-Emitter Voltage (V_{BE})	500-700 mV	100-300 mV
Base-Emitter Reverse Breakdown Voltage (V_{EBO})	3-6 volts	0.5-1.5 volts (high frequency types) 10-100 volts (alloy type)

1. Polarity reversal. The only circuit adaptation required when substituting NPN transistors for PNP is the reversal of supply voltage polarity.

2. Maximum junction temperature rating (T_J(max)). Because of their higher maximum temperature ratings silicon transistors can be operated at higher ambient temperatures than germanium; also, much higher dissipation is possible at normal ambient temperatures. Furthermore, silicon transistors cause far fewer soldering problems.

3. Leakage current. The lower leakage currents of silicon transistors minimize biasing problems at high ambient temperatures, provide better noise performance at low frequencies, and permit operation at much lower current levels than would be possible with comparable germanium devices.

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The combination of the higher dissipation ratings and lower leakage currents of silicon transistors makes it possible to operate over a much wider range of currents than would be feasible with germanium transistors. For example, circuits can be designed with silicon transistors operating at low current and high impedance levels that have very low power consumption; or, by designing for operation at high current levels, it is possible to obtain more high-frequency gain per stage with silicon than with germanium transistors.

4. Cutoff frequency. Since high-frequency silicon devices can be manufactured with excellent yields by the planar process, silicon planar entertainment devices have considerably better high frequency capabilities than germanium devices comparable in price. When designing broadcast receivers with germanium transistors it is customary to use devices whose high frequency characteristics are just adequate to perform the required function, whereas the comparable silicon device has a much higher f_T. As a result, silicon transistors give better performance in the r-f portion of the receiver than germanium devices. In the audio section, on the other hand, because of their high f_T silicon transistors can cause instability by amplifying unwanted internal i-f and r-f frequencies unless care is taken with layout and high frequency filtering.

5. Base-Emitter Voltage (V_{BE}). The higher V_{BE} of silicon transistors is easily taken into account in the design of biasing networks. However, it does lead to some differences in typical component values chosen, especially in battery-operated receivers, as will be discussed in greater detail below in the section on design considerations.

6. Base-Emitter Reverse Breakdown Voltage (V_{EBO}). The V_{EBO} rating is of significance in broadcast receiver applications only in an r-f stage which is fully cut off by reverse agc and the base-emitter junction reverse-biased. Under these conditions the maximum input signal that can be handled is set by the V_{EBO} rating. Since high-frequency devices are required in such an application, silicon transistors have considerably better capabilities for handling high signal levels than comparable germanium devices. Another result of their higher V_{EBO} rating is that silicon transistors are much less subject to damage from the application of reverse high-level transients at their input.

II. DESIGN CONSIDERATIONS WITH SILICON TRANSISTORS

Design of i-f stages. The circuit configurations and principles used in designing receivers with silicon transistors are the same as with germanium devices. Since the silicon transistors used in i-f amplifiers are very-high-frequency devices, the mismatch approach applied in designing with germanium very-high-frequency devices must be used. The matched-design approach used for germanium high-frequency alloy transistors will not work for very-high-frequency devices.

Biasing. The biasing of silicon transistors must be given careful consideration. Because of the low leakage currents of silicon devices I_{CBO} can be largely ignored when operating at junction temperatures similar to those of germanium transistors; however, forms of biasing that take economic advantage of the low leakage result in extremely poor control of the V/I operating point. If reasonably close control of operating point is required, conventional biasing arrangements must be used. Under these circumstances, the higher V_{BE} causes the emitter current in silicon stages to decrease more rapidly with decreasing supply voltage than would a germanium stage. To obtain performance comparable to that of a germanium transistor in this regard a higher voltage drop across the emitter resistor is commonly used in a silicon stage. However, in applications in which a large voltage drop in the emitter circuit is not practicable (e.g., Class-B output stages or receivers operating from a 3V supply) a biasing diode must be used in the lower section of the base divider. Further advantages of using biasing diodes are (1) almost perfect compensation for the effect of variations in ambient temperature on operating point and (2) protection of controlled stages from possible damage by accidental supply polarity reversal.

III. PERFORMANCE DATA ON BROADCAST RECEIVERS BUILT WITH SILICON PLANAR TRANSISTORS

Tables II and III give performance data and component specifications on a broadcast receiver (Model No. 6TR-9A) built with six silicon planar transistors, one silicon bias diode as described above, and one germanium diode. A schematic diagram of the receiver is shown in Fig. 1(a). Figures 2(a), 3 and 4(a) are plots showing the performance of this receiver.

TABLE II

Performance Data on Silicon Receiver Model No. 6TR-9A

Reference power output - 5 mW into 8 Ω unless otherwise specified
Voltage supply - 9 V

Characteristics		Frequency (Kc)	9 V V_{CC}	6 V V_{CC}
Quiescent conditions	Emitter current at:			
	Converter	--	0.4 mA	0.2 mA
	First i-f	--	0.5	0.2
	Second i-f	--	1.5	0.68
	Driver	--	1.0	0.52
	Push-pull amplifier	--	1.0 x 2	0.4 x 2
	No-signal current drain	--	6.0	3.2
Radiated sensitivity		600	110 μV/meter	630 μV/meter
		1000	50	500
		1400	50	400
R-f sensitivity at converter base		600	2.8 μV	
		1000	2.0	
		1400	1.8	
Oscillator emitter injection voltage	Bottom end of band	540	150 mV	
	Top of band	1600	230	
Sensitivity of i-f (455 Kc)	At detector		12,000 μV	
	At second i-f base		900	
	At first i-f base		9	
	At converter base		1.4	
Rejection ratios	I-f rejection	600	70:1	
	Image rejection	600	>80:1	
	Image rejection	1000	>400:1	
	Image rejection	1400	400:1	
Radiated selectivity		600 Kc - 10 Kc	40:1	
		- 5	5.6:1	
		+ 5	18:1	
		+ 10	100:1	
		1000 Kc - 10 Kc	40:1	
		- 5	5.6:1	
		+ 5	18:1	
		+ 10	150:1	
		1400 Kc - 10 Kc	18:1	
		- 5	4.5:1	
		+ 5	5.6:1	
		+ 10	56:1	
Audio (1000 cps)	Maximum power output		230 mW	
	Power output at 10% distortion		190 mW	
	Current drain at max. power output		60 mA	
	Sensitivity at driver amplifier base for 50 mW output		4 mV	

TABLE III

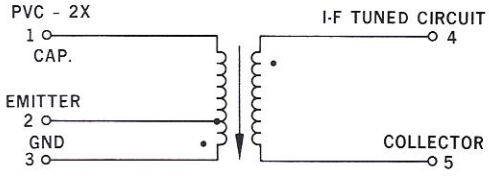
Component Specifications for Silicon Receiver Model No. 6TR-9A

Antenna Coil

Q at 1 Mc = 180 - 250

L = 620 μH used in conjunction with Mitsumi tuning capacitor type PVC-2X or equivalent.

Primary to secondary ratio = 31:1



Terminal	No. of Turns
2 - 3	2
1 - 3	119
4 - 5	22

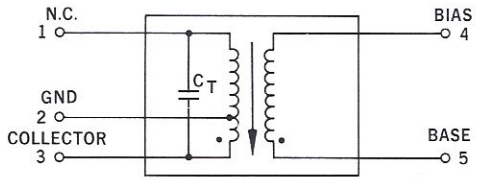
Oscillator Coil (see diagram)

Inductance 365 μH -4% +8%

Q at 796 Kc = 120 min.

I-f Transformer (see diagram below)

	Tuning cap (C_T) (pf ±20 pf)	Frequency (Kc +5% -2.5%)	Unloaded Q (+20% - 10%)	No. of Turns Term. 1 - 2	Term. 2 - 3	Term. 1 - 3	Term. 4 - 5
T_1	180	455	70	138	36	174	4
T_2	180	455	70	80	94	174	7
T_3	180	455	140	105	54	159	50



Driver Transformer

Impedance ratio = 16 K:6 K

Output Transformer

Impedance ratio = 450 Ω:8 Ω

Table IV gives performance data and component specifications on a similar broadcast receiver (Model No. 6TR-9B), whose principal difference is the incorporation of an agc auxiliary diode (Germanium 1N34) between the first i-f stage and the mixer. A schematic diagram of this receiver is shown in Fig. 1(b). Figures 2(b), 3 and 4(b) are plots showing the performance of this receiver. A comparison of Figs. 4(a) and 4(b) shows that the agc figure of merit is greatly improved by the auxiliary diode.

TABLE IV

Performance Data and Component Specifications for Silicon Receiver Model No. 6TR-9B

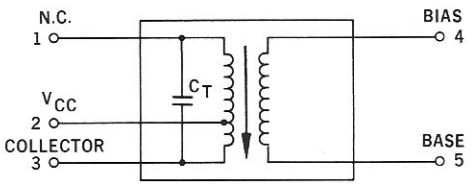
	600 Kc	1000 Kc	1400 Kc
Radiated sensitivity (μV/meter)	30	80	50
10 db signal to noise ratio radiated sensitivity (μV/meter)	170	280	175

I-f transformer specifications

T_3 - same as for Model No. 6TR-9A

T_1, T_2 - same as for Model No. 6TR-9A except for turns specifications:

	No. of Turns Term. 1 - 2	Term. 2 - 3	Term. 1 - 3	Term. 4 - 5
T_1	139	35	174	9
T_2	132	42	174	6



(Oscillator coil, driver transformer (T_4), and output transformer (T_5) have specifications identical to those of Model No. 6TR-9A)

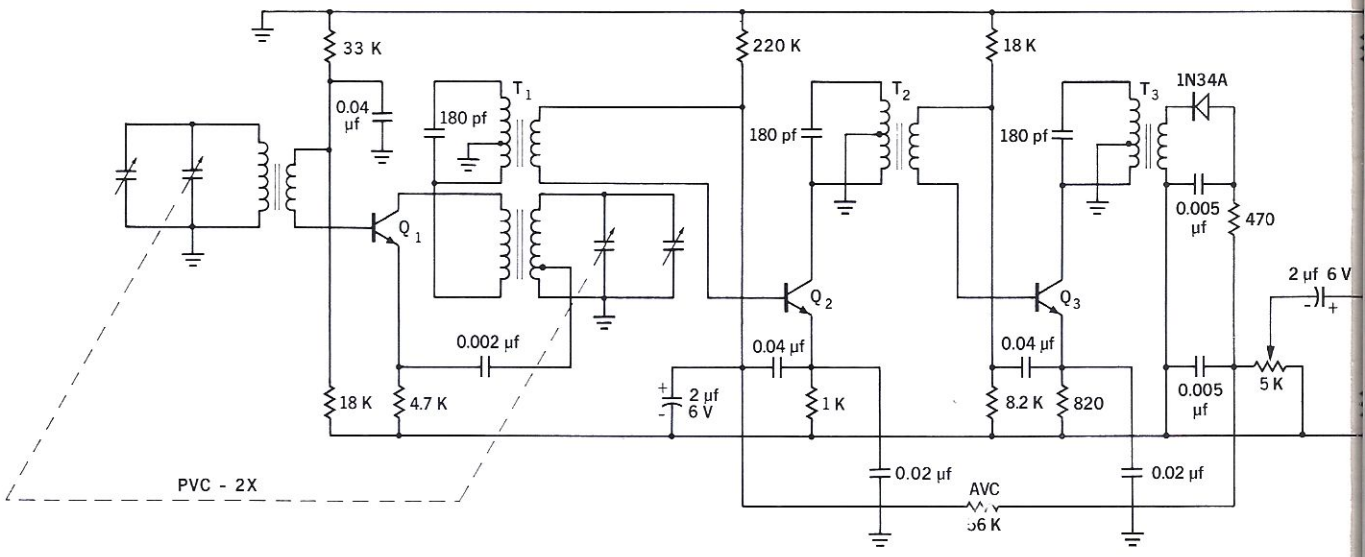


Fig. 1a. Silicon 6-transistor broadcast band receiver Model N

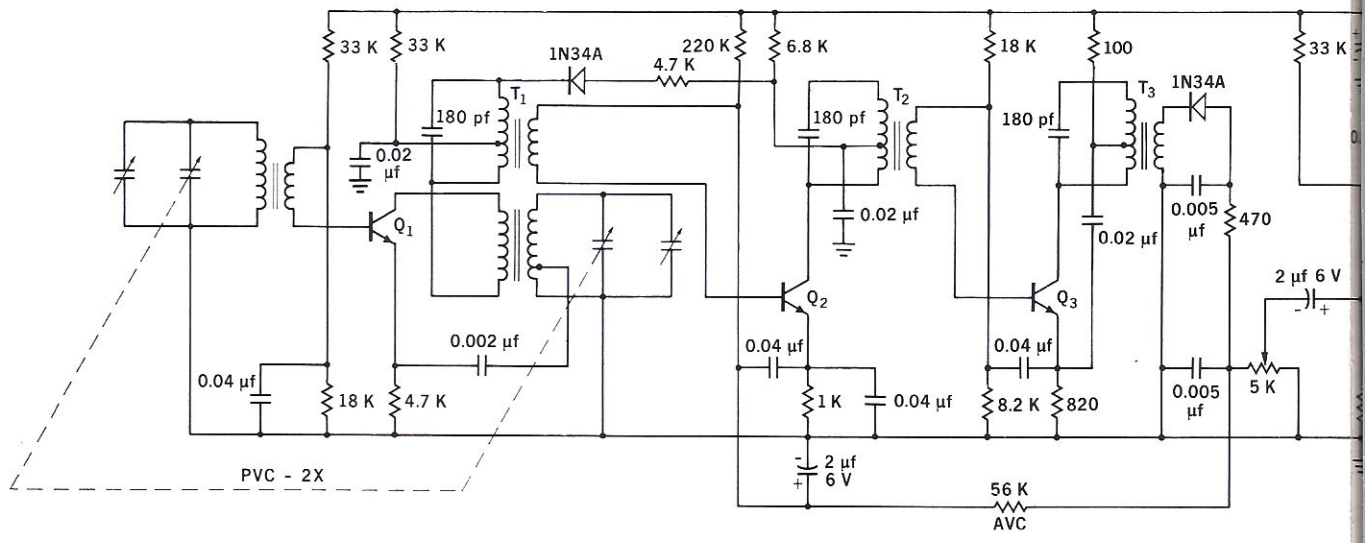


Fig. 1b. Silicon 6-transistor broadcast band receiver Model N

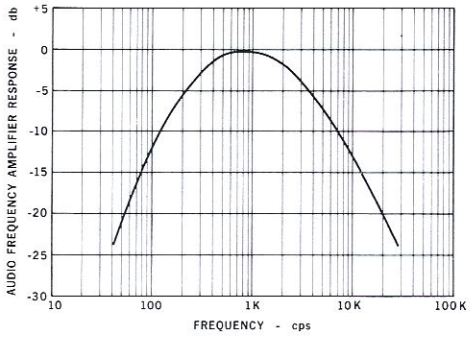
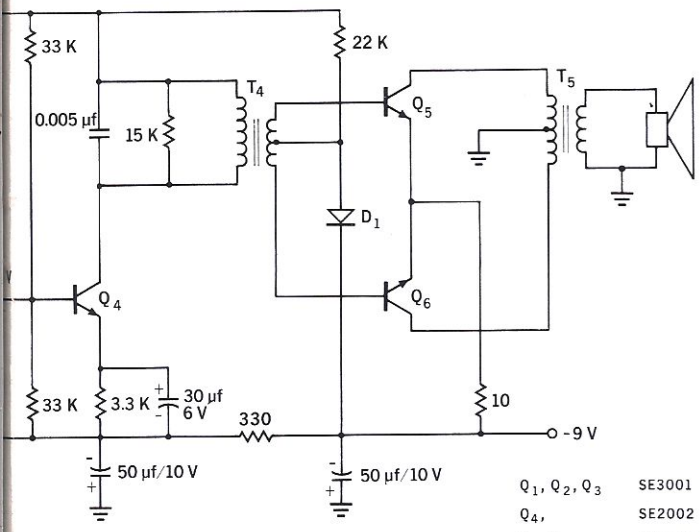


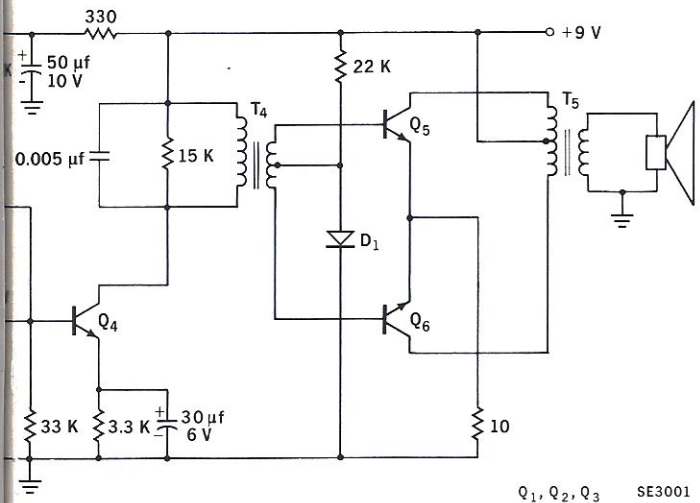
Fig. 2a. Audio frequency output response for Model No. 6TR-9A.

Fig. 2b. Audio freque



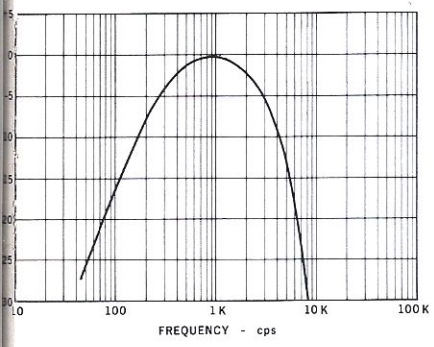
Q_1, Q_2, Q_3	SE3001
Q_4,	SE2002
Q_5, Q_6	SE6002
D_1,	FD-1

No. 6TR-9A.



Q_1, Q_2, Q_3	SE3001
Q_4,	SE2002
Q_5, Q_6	SE6002
D_1,	FD-1

No. 6TR-9B.



quency output response for Model No. 6TR-9B.

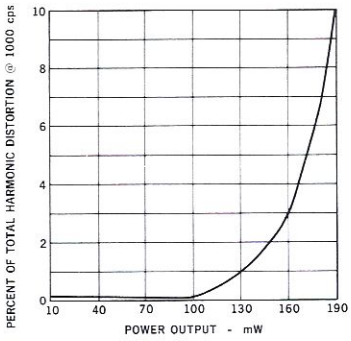


Fig. 3. Output power distortion plot for both receivers.

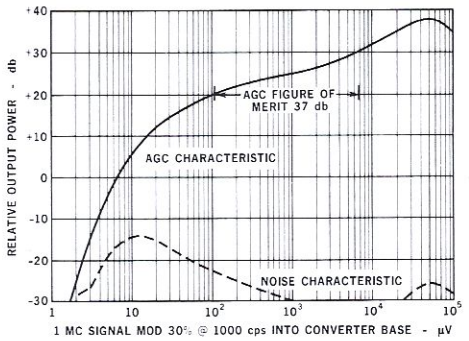


Fig. 4a. AGC and noise performance characteristics for Model No. 6TR-9A.

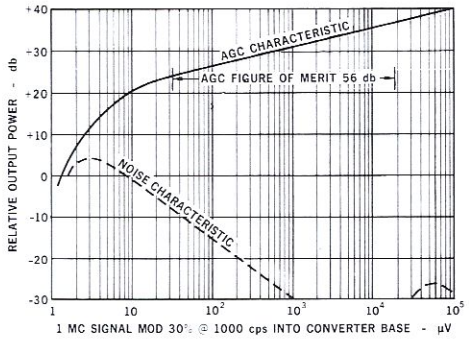


Fig. 4b. AGC and noise performance characteristics for Model No. 6TR-9B.